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Identification of Landslide Potential at UNNES Conservation Park Based on Rainfall and Soil Geology Parameters

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Abstract. Semarang city has a unique morphology with hilly in the south and lowland in the north area. UNNES Conservation Park as aa study area located at the hilly area has a potential of landslide susceptibility with the various level of slope and the type of soil. Furthermore, in the wet season, high intensity of rainfall in this area be considered as the factor for landslides triggering. This article focused analyse the potential for landslides in the study area. A cross section in north area which has steep slope was taken to be analysed. Comparison the manual method using Fellenius and Bishop and a numerical method for SF computation was applied for landslide potential identification. The results of analysis revealed the SF number was 1.746 with the Fellenius method and 1.786 with the Bishop method. Meanwhile, using the numerical method, the SF number is 1.440-1.471. From the result could be concluded the UNNES Park was categorized as stable class for Fellenius and Bishop method and critical class category for numerical method.

1. Introduction

Landslide is a process of soil instability caused by changes in the geological, geomorphic, and hydrological conditions of the area by geodynamic processes, vegetation, land use, and human activities [1]. Landslide movements include flowing, sliding, rolling, falling, spreading, or a combination of the above movements simultaneously where landslides are present all over the place and play a role in the development of the soil surface and sometimes pose a serious threat human lives [2].

Landslide disasters can cause a lot of material loss and loss of life. Based on data from Semarang Regional Disaster Management Authority in 2021, there were 146 landslides out of 432 natural disasters that occurred with 1255 victims and losses reaching 1.18 billion IDR [3].

Rainfall is one of the most significant factors in triggering landslides on slopes which water will infiltrates to the soil through cracks and raises the ground water level which affect the reduction the soil effective stress parameters then it reduces the soil bearing capacity [4][5]. Duration and intensity of the rainfall are important parameters that triggering the occurrence of materials flow [6]. Rainfall-initiated landslides are usually determined as triggering factor for landslide but nowadays, the researcher also considering the antecedent rainfall which could develop the worst pore-water pressure condition which more significant in residual soils with low permeability [7][8]. long-term periods of preparatory precipitation and precipitation not occurring below a critical minimum level that sustains slope imbalance, these parameters indicate conditions that favouring landslide acceleration [9].

Geological structures also affect the occurrence of movements in the soil such as bedrock contact with weathering rocks, cracks, rock layers, and faults. Faults are weak areas that cause rock strength to decrease and cause cracks that allow water to seep in [10]. The discontinuity of geological structureon layer of rock slopes can triggered a slope instability [11]. Type of soils that formed the slope is very important factor to the landslide potential where if the slope is formed by soft soil it will have problems like low bearing capacity and high settlement when load is continuously given [12].

Information on the trends of landslide fatalities and the factors contributing to these trends is essential for policymakers to prioritize measures to reduce landslide fatalities [13]. Analyze the potential for landslides is necessary as a basis for mitigating landslide disasters in the area. The potential for landslides in a area could be assessed from the level of slope stability by calculating the value of Safety Factor (SF) number at the site considered [14].

In this study, the analysis of slope stability was carried out using the slice method and the numerical method using Plaxis 2D. The minimum SF value will be taken as the critical value of the area to determine the potential for landslides in the area.

2. Study Area

Semarang is divided into highlands in the south which is the valley of Mount Ungaran and lowlands in the north dominated with coastal areas. In the southern area has slopes ranging from 15% to more than 40%. Contrastly, in the lowland at the north, the average slope is less than 8% so the terrain is quite gentle. This area is also an industrial center and has a higher population density than the southern part. The UNNES Conservation Park area is located in Gunung Ledek, Gunungpati District, Semarang City with the research point located at coordinates 7° 2' 29.242” South Latitude and 110° 23' 0.532” East Longitude which can be seen in Figure 1.

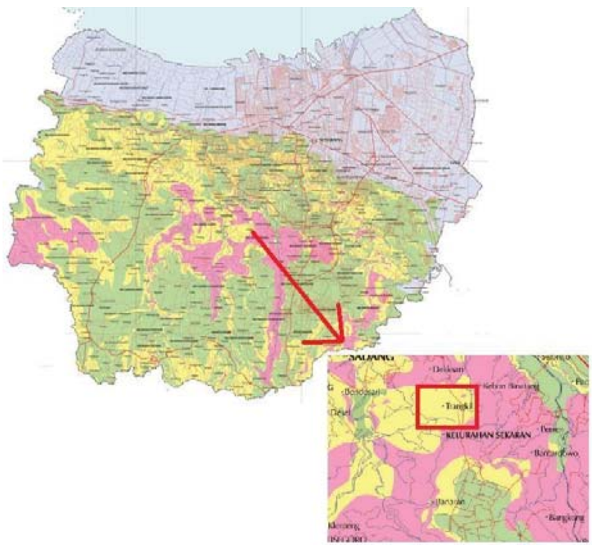

Figure 1. Location of study area [15].

UNNES Corsevation Park is planned to become a Science and Techno Park (STP), which is an integrated area based on science and technology that combines elements of developing science and technology, market needs, and strengthening regional competitiveness [16]. The study area is a hilly land and located at a fault line with fractures on the surface of the road near the location [17]. Previous research in the area has shown that UNNES Corservation Park is composed of layers of clay with fractures scattered at several points. Based on field observations, UNNES Park experienced landslides, especially near the road, which can be seen in Figure 2.

The Gunungpati area has a steep slope of up to 40% in some places with the rock types making up the slopes dominated by clay and volcanic rocks which are easily weathered and absorb a lot of water, this causes the soil to easily become saturated [18].

Figure 2. Condition of UNNES Conservation Park.

3. Data and Method

3.1. Slope Topographic Map

The topographic map of the research location is intended to determine the slope and cut shape of the slope to be reviewed. The data used are geoelectrical measurement points scattered throughout the UNNES Conservation Park area. The elevation of each point is obtained using Google Earth Pro by entering the coordinates of the point.

The red line points out the cross section of considered study area. Topographic maps of UNNES Conservation Park could be seen in Figure 3 and Figure 4.

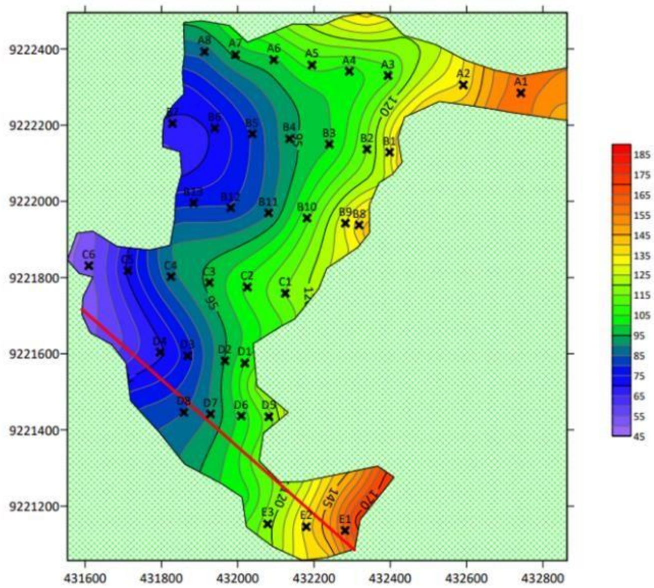

Figure 3. Topographic map of Conservation Park.

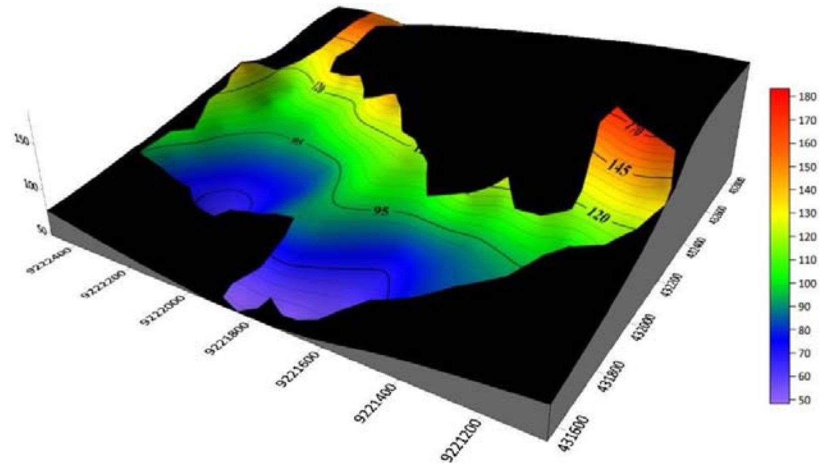

Figure 4. 3D Topographic map of Conservation Park.

The topographic map depicts the contour conditions of the UNNES Conservation Park to assist in finding the slope and the shape of the slope. The red line shows the trajectory of the slope under study and a cross-sectional drawing of the slope is made. Area with red colour indicate have steep slope. In contrasty, for the gentle slope indicated by bule colour. The width of the contour line describes the steepness of the slope where the closer the contour line, the steeper the slope and the more sparse the contour line, the more gentle the surface of the slope. The slope of the UNNES Park studied has a track length of 964 meters with a ground height from 51 meters above sea level to 163 meters above sea level.

3.2. Soil Parameters and Layers

Soil parameter values obtained by the process of correlation between soil types from the results of the geoelectric test from the point closest to the slope trajectory. The following description of the soil layers on the slopes can be seen in Table 1 and the soil layers distribution across the slope can be seen in Table 2 and Figure 5.

The soil parameters used in the slice method and Plaxis are unit weight of soil (γ), cohesion (c), shear angle (φ), modulus of elasticity (E), and Poisson's ratio (v'). the following soil parameter values can be seen in Table 2.

Table 1. Soils descriptions.

Layer Name	Geoelectric Test Data (ρ)	Description
Layer 1	27.8	Sandy clay
Layer 2	3.36	Clay

Table 2. Soil layers depth.

Distance (m)	Depth (m)	
	Layer 1	Layer 2
0 – 52.85	1.4	38.6
52.85 – 136.7	1.74	38.26
136.7 – 322.5	3.11	36.89
322.5 – 587.6	3.19	36.81
587.6 – 710.6	8.7	31.3
710.6 – 808.6	8.37	31.63
808.6 - 943	8.38	31.62

Table 3. Soils parameters.

Parameter	Soil type		Unit
	Clay	Sandy Clay	
γ_d	16	18	kN/m³
γ_{sat}	18	20	kN/m³
E	25000	30000	kN/m²
v'	0.3	0.3	-
c'	25	12	kN/m²
ϕ	8	20	°

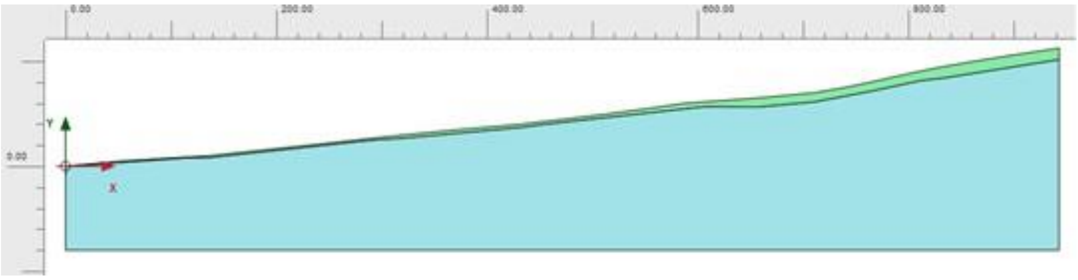

Figure 5. Soil Layers of the slope.

3.3. Slope Stability Analysis Using the Slice Method

The slice method is a commonly used method for slope stability analysis with manual calculations. For the analysis of the stability of slopes of arbitrary shape and composition various approximate methods have been developed. Most of these assume a circular slip surface. Some examples of the slice method are the Fellenius method and the Bishop simplified method [14]. The method used the failure criterion, The Mohr-Coulomb Theory, which assumed that the shear strength and the normal stress have linear relationships [19].

3.3.1. Fellenius Method

The Fellenius method or the Ordinary Method of Slice is the oldest method for performing slope analysis. In the Fellenius method, the slope is drawn with curved lines depicting the slope failure surface which will divided into several sections.

In this method it is assumed that there are no forces acting between the slices and no forces acting in the horizontal direction. The other forces are assumed to be on the soil wedge and there are forces of soil weight (W_n), normal stress (σ'), and shear stress (τ) at the bottom of the slice. The weight of the soil in each slice is obtained from the area of the slice of the soil multiplied by the specific gravity of the soil so that the weight of the soil slice is in the direction of gravity. The normal force (N_r) on each slice can be calculated as the weight of the soil (W_n) by observing the direction of the force perpendicular to the slope surface [14]. The equation for the SF value using the Fellenius method is described as follows [20]:

$$SF = \frac{\sum_{n=1}^{n=p}(c'\Delta L_n + W_n \cos\alpha_n \tan\phi')}{\sum_{n=1}^{n=p} W_n \sin\alpha_n} \quad (1)$$

$$W_n = A_n . \gamma \quad (2)$$

$$\Delta L_n = b_n(\cos\alpha_n)^{-1} \quad (3)$$

where,

SF	=	Safety Factor,
c'	=	Cohesion (kN/m²),
ΔL_n	=	Length of slice surface (m),
W_n	=	Weight of slice (kN/m),
α_n	=	Angle of inclination (°),
ϕ'	=	Friction angle (°),
A_n	=	Area of slice (m²),
γ	=	Unit weight of the soil (kN/m³),
b_n	=	Width of slice (m),
r	=	Circle radius (m).

3.3.2. Bishop Simplified Method

Bishop's method is the most frequently used method in slope stability analysis which was developed from the Fellenius method. This method uses the same landslide model approach as the Fellenius method. The forces that occur between soil slices are no longer ignored, but are assumed to have a horizontal direction. The equation for the SF value using the Bishop simplified method is described as follows [20]:

$$\mathrm{SF} = \frac{\sum_{n=1}^{n=p}(c'\Delta L_n + W_n \cos\alpha_n \tan\phi')}{\sum_{n=1}^{n=p} W_n \sin\alpha_n} \tag{4}$$

In calculating the SF value using the bishop method, trial and error was carried out on the Fs value until the same SF value was obtained on both sides of the formula.

3.4. Numerical analysis simulation

Numerical analysis simulation was conducted by using Plaxis software. Plaxis is a geotechnical analysis program, especially for overcoming soils using finite elements that is capable of performing analyzes such as settlement, stresses, safety figures, and failure patterns with results that are close to the actual behaviour [21][22].

4. Result

4.1. Fellenius Method

In the Fellenius method, it is necessary to make a cross-sectional model of failure surface of the slope based on the cross-sectional shape of the slope by determining the center point and making a circle that covers the entire slope, the part of the slope that is in the circle is then divided into several sections that do not need to be equal length. The lines from the center of the circle to each center of slice is drawn and measured its angle to the direction of gravity. The width ang area of each slice also measured. Model of trial failure surface can be seen in Figure 6.

After all the elements of the equation have been obtained then all data from the trial failure surface and soil parameters are inputted to the equation so that the SF value of the slope can be calculated. From the results of calculations using the Fellenius method, the SF value of 1.746 is obtained. The calculation of the SF value using the Fellenius method can be seen in Table 4.

4.2. Bishop Simplified Method

Bishop simplified method using the same data and model trial surface failure on Fellenius method with the difference is this method need to do trial and error of SF value until SF value on end result is same as the trial value. Trial SF value start at 1 and gradually increasing or decreasing the trial value until matched it the result. After calculating using Bishop simplified method, SF value of 1.786 is obtained. The calculation of the SF value using the Bishop simplified method could be seen in Table 5.

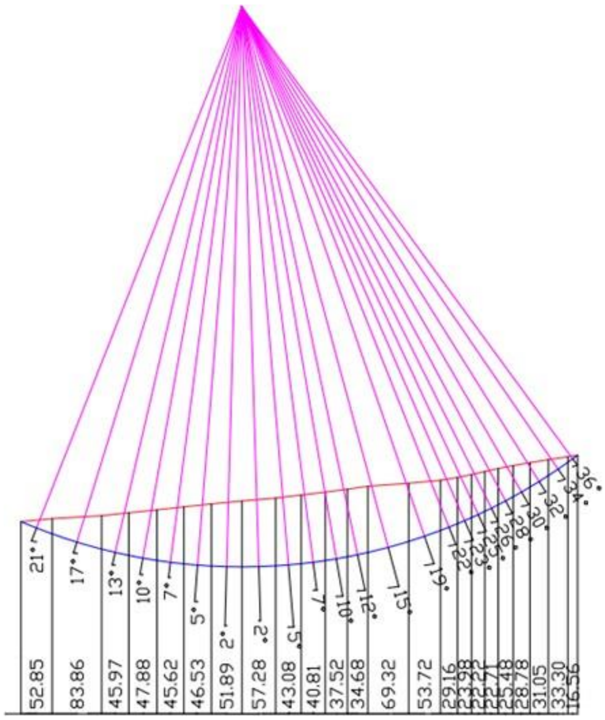

Figure 6. Trial failure surface.

Table 4. SF calculation using Fellenius method.

Slice	c' (kN/m^2)	Φ (deg/^{0})	An (m^2)	γ (kN/m^3)	bn (m)	Wn (kN/m^2)	αn (deg/^{0})	ΔLn (m)	Wn*sinα (kN/m^2)	(c'ΔLn+Wn. cosα.tanΦ)	SF
1	12	20	697.8	20	52.8	13956.8	21	49.3	5001.7	5334.5	
2	12	20	3515.5	20	83.9	70311.0	17	80.2	20556.9	25435.2	
3	12	20	2972.4	20	46.0	59448.9	13	44.8	13373.1	21620.6	
4	12	20	3796.2	20	47.9	75923.7	10	47.1	13184.0	27780.0	
5	12	20	4156.6	20	45.4	83131.8	7	45.1	10131.2	30573.2	
6	12	20	4709.9	20	46.5	94197.1	5	46.3	8209.8	34710.7	
7	12	20	5646.0	20	51.9	112919.8	2	51.9	3940.8	41696.7	
8	12	20	6512.3	20	57.3	130245.3	2	57.2	4545.5	48063.5	
9	12	20	4993.1	20	43.1	99861.6	5	42.9	8703.5	36723.4	
10	12	20	4752.4	20	40.8	95047.9	7	40.5	11583.4	34822.8	
11	12	20	4336.7	20	37.5	86733.7	10	36.9	15061.2	31532.2	
12	12	20	3923.1	20	34.5	78462.1	12	33.7	16313.2	28338.7	1.746
13	12	20	7351.7	20	69.3	147034.8	15	67.0	38055.4	52496.3	
14	12	20	4954.2	20	53.7	99083.1	19	50.8	32258.3	34708.0	
15	12	20	2382.4	20	29.1	47647.9	22	27.0	17849.2	16403.0	
16	12	20	1821.1	20	24.0	36423.0	23	22.1	14231.6	12467.9	
17	12	20	1568.2	20	22.2	31363.8	25	20.1	13254.9	10587.6	
18	12	20	1470.6	20	22.7	29411.9	26	20.4	12893.3	9866.5	
19	12	20	1451.6	20	25.3	29032.1	28	22.3	13629.8	9598.0	
20	12	20	1356.2	20	28.6	27124.7	30	24.8	13562.3	8847.1	
21	12	20	1071.1	20	31.1	21421.9	32	26.3	11351.9	6928.2	
22	12	20	612.0	20	33.1	12240.6	34	27.5	6844.9	4023.0	
23	12	20	78.4	20	16.4	1567.1	36	13.2	921.1	620.4	
			Sum (Σ)					897.6	305457.0	533177.3	

Table 5. SF calculations using Bishop simplified method.

Slice	c' (kN/m^2)	Φ (deg/^{0})	An (m^2)	γ (kN/m³)	bn (m)	Wn (kN/m²)	αn (deg/^{0})	Wn*sinα (kN/m²)	Trial SF Value	(c.bn+Wn.tanΦ) / cosαn+ (tanϕ.sinαn)/F	SF
1	12	20	697.8	20	52.8	13956.8	21	5001.7		5676.50	
2	12	20	3515.5	20	83.9	70311.0	17	20556.9		26181.42	
3	12	20	2972.4	20	46.0	59448.9	13	13373.1		21749.65	
4	12	20	3796.2	20	47.9	75923.7	10	13184.0		27650.09	
5	12	20	4156.6	20	45.4	83131.8	7	10131.2		30276.55	
6	12	20	4709.9	20	46.5	94197.1	5	8209.8		34363.67	
7	12	20	5646.0	20	51.9	112919.8	2	3940.8		41452.51	
8	12	20	6512.3	20	57.3	130245.3	2	4545.5		47782.05	
9	12	20	4993.1	20	43.1	99861.6	5	8703.5		36356.25	
10	12	20	4752.4	20	40.8	95047.9	7	11583.4		34484.89	
11	12	20	4336.7	20	37.5	86733.7	10	15061.2		31384.85	
12	12	20	3923.1	20	34.5	78462.1	12	16313.2	1.786	28389.31	1.786
13	12	20	7351.7	20	69.3	147034.8	15	38055.4		53352.05	
14	12	20	4954.2	20	53.7	99083.1	19	32258.3		36277.47	
15	12	20	2382.4	20	29.1	47647.9	22	17849.2		17629.07	
16	12	20	1821.1	20	24.0	36423.0	23	14231.6		13542.79	
17	12	20	1568.2	20	22.2	31363.8	25	13254.9		11771.14	
18	12	20	1470.6	20	22.7	29411.9	26	12893.3		11109.37	
19	12	20	1451.6	20	25.3	29032.1	28	13629.8		11107.83	
20	12	20	1356.2	20	28.6	27124.7	30	13562.3		10554.30	
21	12	20	1071.1	20	31.1	21421.9	32	11351.9		8545.19	
22	12	20	612.0	20	33.1	12240.6	34	6844.9		5146.02	
23	12	20	78.4	20	16.4	1567.1	36	921.1		825.68	
Sum(Σ)								305457.0		545608.6	

4.3. Numerical analysis simulation

Analysis of the value of SF by using numerical analysis simulation was carried out in three different conditions. The first condition is made with dry soil conditions, the second condition is made with soil conditions that have a groundwater, and the third condition is made with infiltration conditions with the assumption of the top three meters of soil is saturated. Modeling of flow conditions for each experimental condition can be seen from Figure 7 to Figure 9.

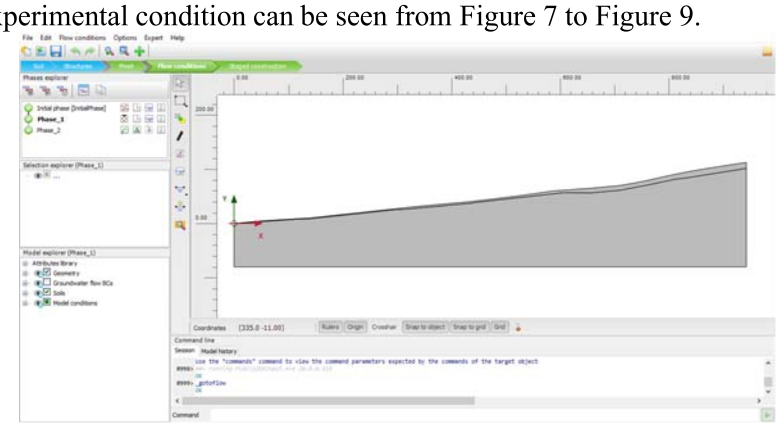

Figure 7. Flow condition for dry condition soil.

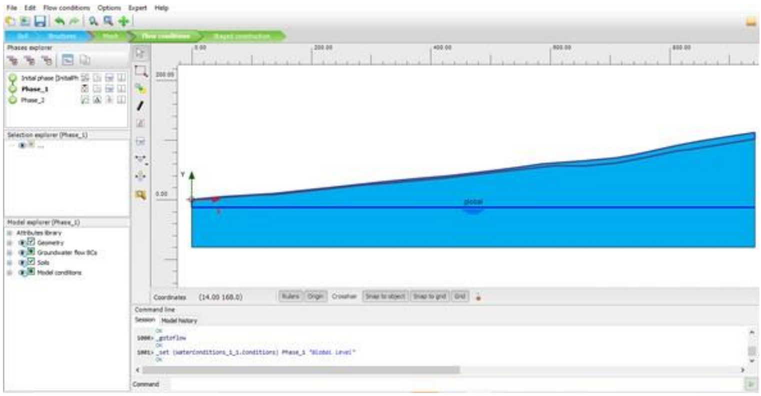

Figure 8. Flow condition for soil with groundwater.

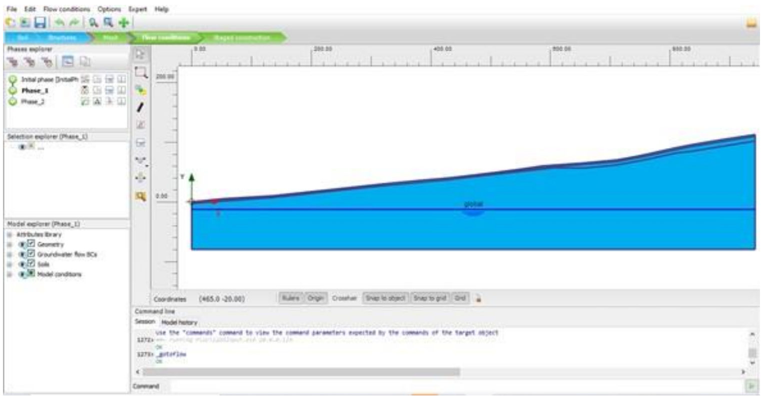

Figure 9. Flow condition for soil with infiltration.

After the Plaxis model is made, the next step is to determine the distribution of elements in the soil structure with a mesh. The mesh is created with the generate mesh menu with the medium distribution level and the coarseness factor set at 0.5. Then the analysis process is continued by entering the flow conditions according to the respective experimental conditions.

The last input process is staged construction. Each phase has a different type of calculation with the same configuration for all soil conditions in this experiment. For the initial phase a gravity loading calculation type is used, in the deformation phase a Plastic calculation type is used, and in the last phase a safety calculation type is used. The order of the experimental phases can be seen in Figure 10.

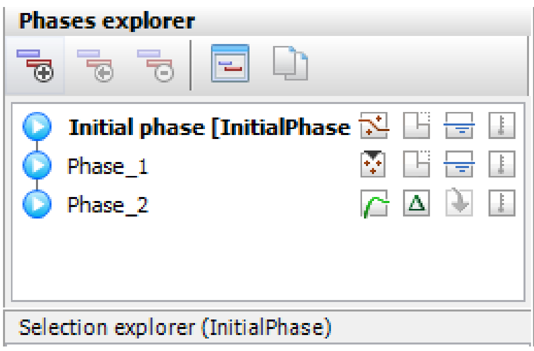

Figure 10. Phases order.

After all phases have been inputted, calculations are carried out for all phases by not selecting nodes. After the calculation process for all phases is complete, each phase is reviewed for deformation and safety factors. The deformation and safety factor values can be seen in Figures 11 to 16.

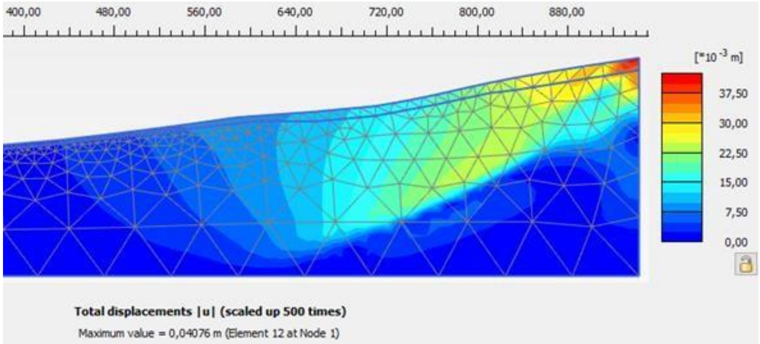

Figure 11. Soil deformation in dry conditions.

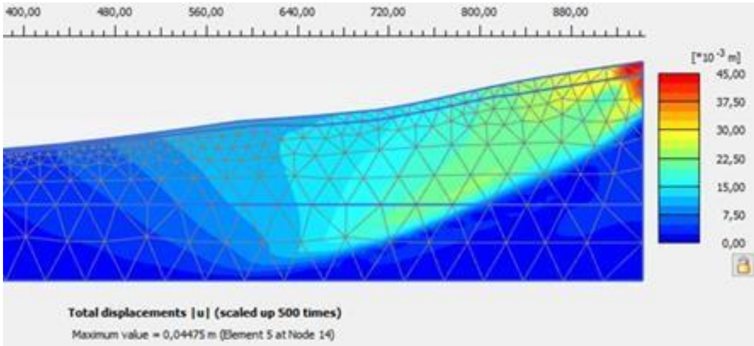

Figure 12. Soil deformation with groundwater condition

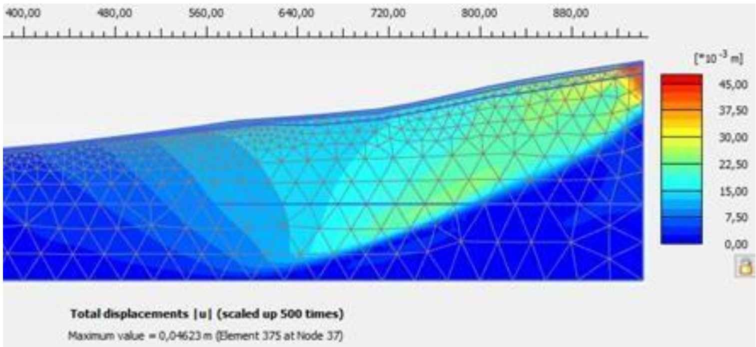

Figure 13. Soil deformation with infiltration condition.

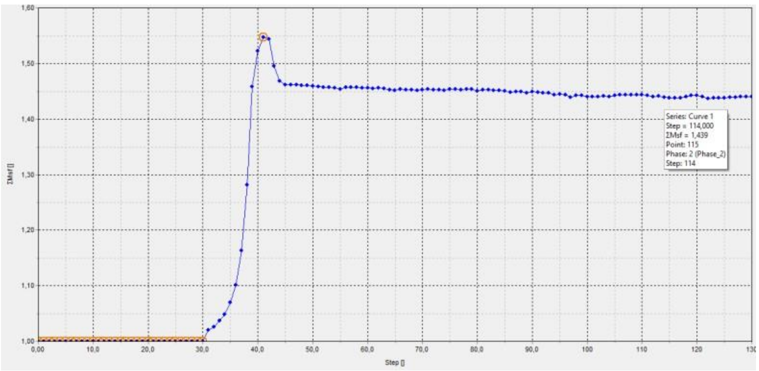

Figure 14. SF in dry soilcondition.

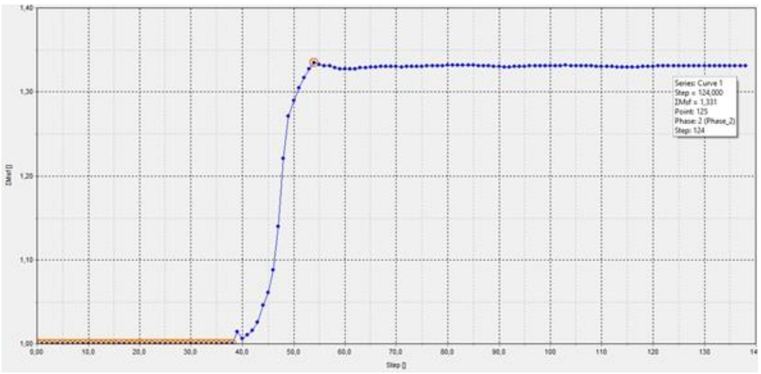

Figure 15. SF in soil with groundwater condition.

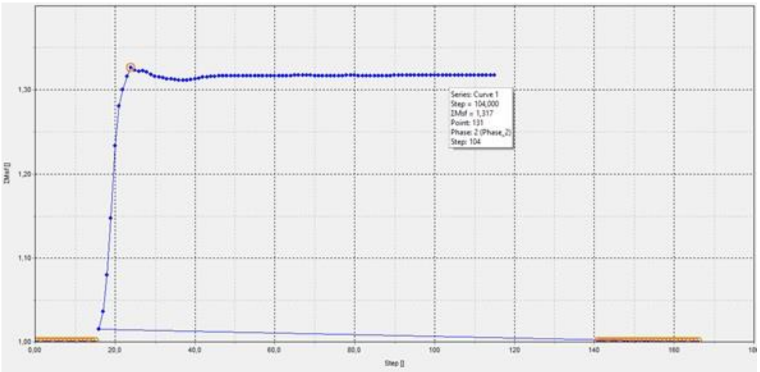

Figure 16. SF in soil with infiltration condition.

5. Identification of Landslide Potential

From the analysis of the SF value using the slice method in the form of the Fellenius and Bishop simplified method and using Plaxis, the SF value and soil deformation are obtained which can be seen in Table 6.

After obtaining the SF value using the slice method and Plaxis, then the Fs value is checked with the safety number classification table in Table 6 to determine the classification of the landslide potential of the area.

Table 6. Deformation and SF recap.

Method	Deformation (cm)	SF
Fellenius	-	1.746
Bishop simplified	-	1.786
Plaxis (Dry)	4.076	1.439
Plaxis (Groundwater)	4.475	1.331
Plaxis (Infiltration)	4.623	1.317

Table 7. SF values and landslide intensity [23].

Nilai Fs	Classification
< 1.07	labile class (landslides are frequent/usual)
1.07 < Fs < 1.5	Critical class (landslides have happened)
>1.5	Stable class (landslides are rarely occured)

In the identification of potential landslides, the smallest SF value from the slice method and Plaxis as the critical condition of the slope is used. In the slice method, the SF value of 1.746 from the Fellenius method is used, according to the classification table the value is included in the slope classification with a stable class. Using the numerical method, the smallest SF value is 1.317 which according to the classification table is included in the slope of the critical class. The results of the analysis of the SF value using the manual method produce an SF value that is less accurate than the numerical method because the Fellenius and Bishop methods use assumptions and simplifications to facilitate calculations.

6. Conclusions

In the analysis of slope stability and identification of potential landslides, it can be concluded that:

1. From the slope stability analysis using the manual method, the Fs value is 1.746 using the Fellenius method and 1.786 using the simplified Bishop method. While using Plaxis the Fs value in dry conditions is 1.439, in conditions with a groundwater level of 1.331, and in infiltration conditions of 1.317.
2. From the results of the Plaxis, it is known that in dry conditions the slope has the smallest soil deformation, which is 4.076 cm. In conditions with a groundwater, the deformation of the soil increases to 4.475 cm. In soil conditions with water infiltration, the results showed the highest soil deformation of 4.623 cm.
3. From the identification of potential landslides, it is found that the UNNES Park area is included in the critical class using the Fs value with Plaxis which results are more accurate.

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